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New generation of functionalized bipyrazolic tripods: synthesis and study of their coordination properties towards metal cations

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ABSTRACT

A simple and easily synthesis of new generation of *N*-donor bipyrazolic tripods by coupling of functionalized pyrazole derivatives and an appropriate primary amine derivative via condensation or nucleophilic substitution reaction is presented. The complexation capacity of these compounds towards bivalent metal ions (Hg^{2+}, Cu^{2+}, Pb^{2+}, Cd^{2+}) and alkaline metal ions (Li^{+}, Na^{+}, K^{+}) were investigated using the liquid–liquid extraction process. The percentage limits of extraction were determined by atomic absorption measurements.

1. Introduction

Metal ions play an essential role in many biological processes, and deficiency, unusual accumulation or imbalance of metal ions may lead to biological dysfunctions.[1–5] Some metals, especially heavy metals, do not seem to be essential for the functioning of mammals. Nevertheless, because of their competition with essential metals for binding with proteins, heavy metal ions are potent enzyme inhibitors exerting toxic effects on living systems.[6–9] Redistribution of these metals by man through his industrial society constitutes a major health hazard.[10] In this sense, lead, mercury and cadmium are considered to be major pollutants. Therefore, the design of selective extractants for the separation of bivalent metal cation is one of the key problems in wastewater reprocessing. Pyrazole derivatives are the subject of several studies. They are used in different fields, such as pharmacology,[11–14] biology,[15–19] catalysis,[20,21] electronics[22,23] and particularly, they are used to remove the divalent metal ions, Hg^{2+}, Cu^{2+}, Pb^{2+} and Cd^{2+} ions from aqueous solution containing either a single metal species or a mixtures of metal ions.[24–30] Recently, we have developed and studied several pyrazolic tripods derivatives.[31–40] These ligands are considered as a potential electron donating because of their two sp^2 and sp^3 hybridized amine nitrogen atoms where the electronic doublets of these three donor sites are organized according to a pyramidal form for complexing metal. Regarding the chemical application of these prepared ligands,[31–40] they are characterized by a good and selective affinity towards the transition metals,[31–35] and have an important catalytic[26–29] and pharmacological properties.[40,41] These chemical applications depend on the lateral chain nature of the ligands. In fact, it is reported in the literature that the presence of a donor atom in a side chain of lariat ethers increases the binding ability of the macrocycle towards the cations.[42–44] Furthermore, ligands with side arms attached to nitrogen (*N*-pivot lariat ethers) instead of a carbon (C-pivot lariat ethers) present best binding properties. This bonding improvement could be attributed to the high flexibility of the side chain with nitrogen, which gives to the donor site a best binding capacity.[45] Therefore, it is very interesting to increase the electron density on the lateral chain of the tridentate ligands to study their extraction ability towards the metal ions. On the other hand, the presence of a functional chain also provides to these ligands the possibility of being immobilized on the surface of a solid material by covalent bond or to elaborate some membranes including these tripods in their structures by polymerization.

For these reasons, we report in this paper the synthesis of new functionalized pyrazolic tripods, starting from the pyrazolic

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derivatives **2** and **4**, with different side chains: primary alcohol (**6a**, **6c**), secondary alcohol (**3a**, **6b**), alkyl chain (**6e**) vinyl benzene group (**6d**) and alkenyl group (**3b**) as reported in Fig. 1, to study the influence of the side chain nature of these new tripods on their complexing properties towards bivalent metal ions (Hg^{2+}, Cu^{2+}, Pb^{2+}, Cd^{2+}) and alkaline metal ions (Li^{+}, Na^{+}, K^{+}) using a - liquid–liquid extraction process. The relative capacities of these receptors in extracting these cations were determined by the measurement of extracted cation percentage by atomic absorption.

Ligands **3a**,**b** were prepared by nucleophilic substitution reaction of compound **2** and the different amines. First, the precursor 3-chloromethyl-1,5-dimethylpyrazole **2** was prepared from **1** in three steps following the procedure reported in the literature.[46,47] Compound **3a** was obtained in good yield (85%) by treating the chloro derivative with the commercially available 1-aminopropan-2-ol in a ratio of 2/1 under reflux using sodium carbonate as base. Compound **3b** was prepared in 75% yield according to the procedure described above by reacting allylamine with the synthon chloride (Scheme 1).

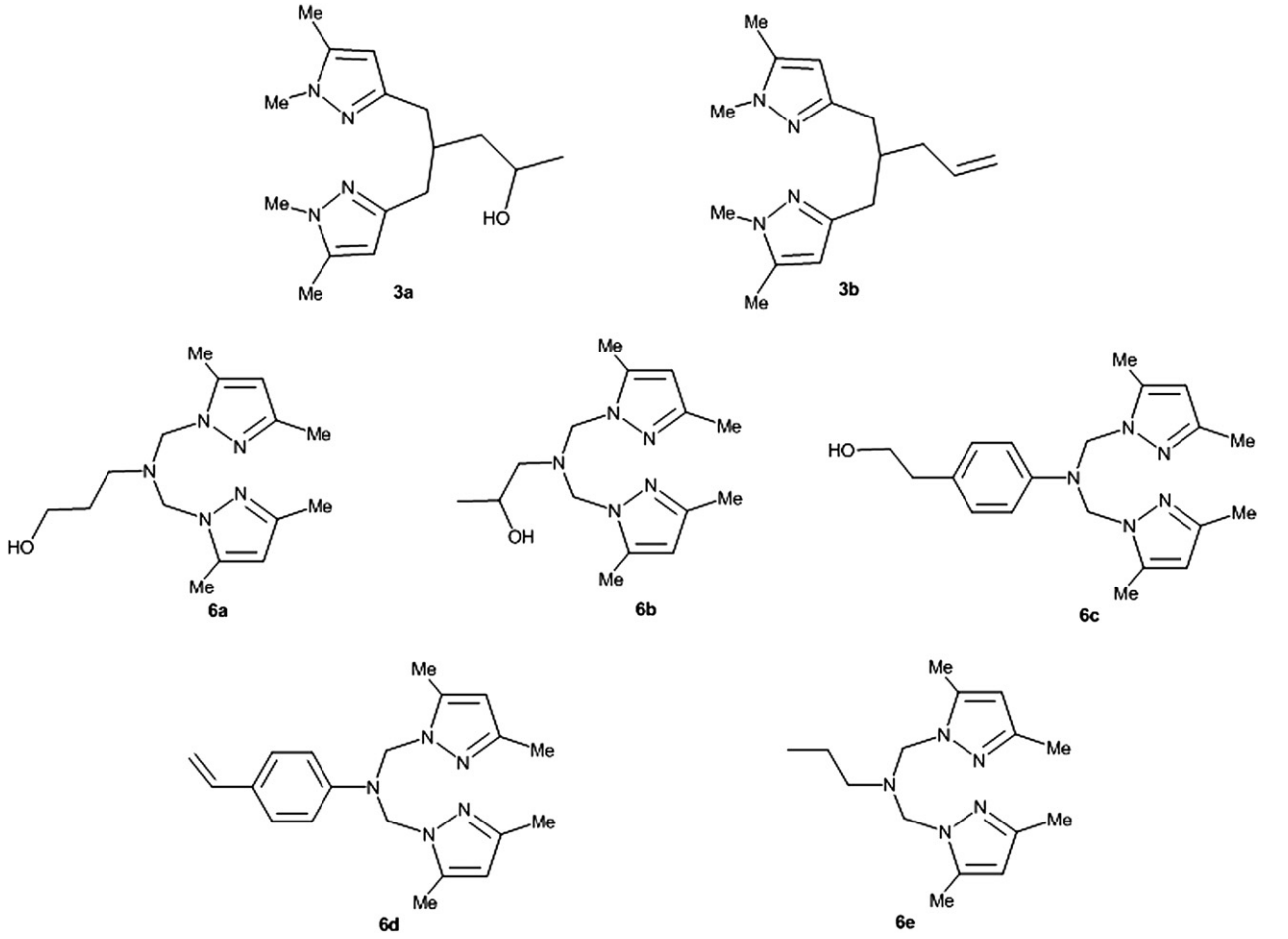
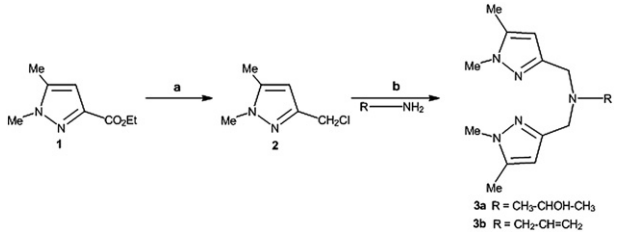


Fig. 1. General structures of functionalized bipyrazolic tripods.

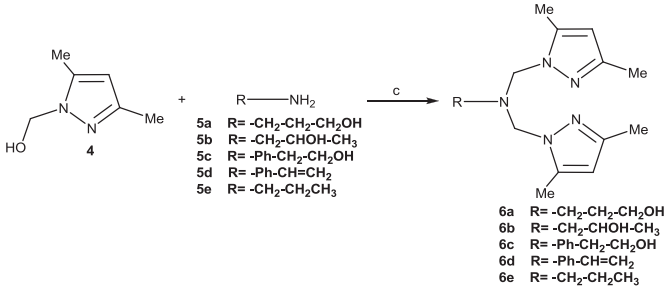
2. Results and discussion

2.1. Synthesis

The synthesis of **3a**,**b** and **6a**–**e** ligands was obtained following the procedure reported in Schemes 1 and 2. The synthetic path depends on the nature and the position of the functional group in the starting pyrazolic derivatives.



Scheme 1. Synthesis of ligands **1** and **2**. Reagents and conditions: (a) **1**—$^{t}BuO^{-}$ K^{+}, MeI, **2**—$LiAlH_4$, **3**—$SOCl_2$; (b) H_2N–R.



Scheme 2. Synthesis of ligands **1**–**5**. Reagents and conditions (c) CH_3CN, reflux, 6 h.

On the other side, the tripods **6a**–**e** were prepared by condensation of **4** with different amines **5a**–**e** (Scheme 2).

N-Donor tripodal ligands **6a**, **6b** and **6d** were prepared via the condensation reaction of di-substituted 1-(hydroxylmethyl)-3,5-dimethyl pyrazole **4**[48] with a series of primary amines as 3-

aminopropanol, 1-aminopropan-2-ol and *para*-aminophenyl ethanol in acetonitrile as solvent for 6 h under reflux to afford the expected tripods in high yield (about 75–85%). Tripods **6a** and **6b** display an alkyl chain functionalized, respectively, by primary and secondary hydroxyl groups. However, tripod **6c** presents phenyl ethoxy group. Tripod **6d**, which exhibits a polymerisable styrenic double bond, was prepared in 70% yield by coupling vinyl aniline with pyrazolic precursor **4** in acetonitrile but at room temperature for 2 days because of the low reactivity of the styrenic group. To evaluate the possible effect of a donor heteroatom in the side chain on the cations binding, another tripodal compound **6e** was prepared without any donor atom in a side chain by condensation of precursor **4** with the propylamine, according to the same procedure reported above. All compounds **3a**,**b** and **6a**–**e** were characterized by ^{1}H NMR, ^{13}C NMR, mass spectroscopy and elemental analyses.

2.2. Liquid–liquid extraction of individual cations

In order to study the capacity of the prepared pyrazolic tripods **3a**,**b** and **6a**–**e** to extract Hg^{2+}, Cu^{2+}, Pb^{2+}, Cd^{2+}, Li^{+}, Na^{+} and K^{+} cations, aqueous solutions (7.10^{-5} M in each) containing bivalent metal ions Hg^{2+}, Cu^{2+}, Pb^{2+}, Cd^{2+} and alkaline metal ions (Li^{+}, Na^{+}, K^{+}) as nitrate metals were extracted with 7.10^{-5} M solutions of ligands **3a**,**b** and **6a**–**e** in chloroform. The percentage limit of extraction was assessed by measuring the concentration of cations in the aqueous solution by atomic absorption. The temperature and pH remained constant during all the experiments (25 °C; pH=7). The extraction results are reported in Table 1.

Table 1
Yields of extraction of various alkali and bivalent metal ions

	Mercury (1.10 Å)	Copper (1.20 Å)	Lead (1.20 Å)	Cadmium (0.92 Å)	Lithium (0.80 Å)	Sodium (0.98 Å)	Potassium (1.33 Å)
3a	48	36	16	25	0	0	0
3b	40	75	32	16	0	0	0
6a	50	52	60	15	0	0	0
6b	56	35	45	13	0	0	0
6c	54	60	72	22	0	0	0
6d	52	40	65	20	0	0	0
6e	55	30	48	17	0	0	0
7	42	95	40	21	0	0	0
8	45	33	20	20	0	0	0

Previous studies[29,32] have demonstrated that the acyclic pyrazoles extract only the transition metal cations. However, the macrocyclic pyrazolic compounds are expected to form stable complexes with transition and alkali metals. Herein, the results reported in Table 1 show that the synthetized acyclic tripods **3a**,**b** and **6a**–**e** present a selective affinity for only the transition metal cations and no complexation was observed towards the alkali cations.

To elucidate the effect of the donor oxygen atom and the allylic double bond of the lateral chain on the complexation of these metals, we compared the extraction yields of ligands **3a** and **3b** with the extraction results obtained from tripods **7** and **8** (Fig. 2)

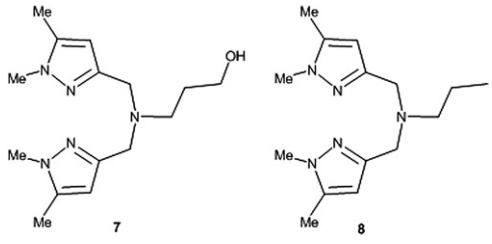


Fig. 2. Structures of tripods **7** and **8**.

already reported in the litterature.[31,32] Tripod **7** has a primary alcohol function on the lateral arm while the tripod **8** has an alkyl saturated chain, without any donor atom.

Tripods **3a**,**b** display a good complexation affinity towards Hg^{2+} cations. This is probably due to the great donor effect of the sp^2 hybridized pyrazolic nitrogen, and also to the disposition of the three nitrogen atoms allowing the complexation of the metal. Indeed, the limit values of the Hg^{2+} extraction are independent to the nature of the lateral arm on the pyrazoles. As reported in Table 1, tripod **7** introduces high affinity to complex Cu^{2+} and the limit value of Cu^{2+} extraction is high ($\approx$95%). This result can be explained by the participation of hydroxyl oxygen of the lateral arm in complexation's phenomenon. The less important extraction value of ligand **3a** ($E\approx$36%) is probably due to the non flexible character of the secondary hydroxyl group in this structure. This result is confirmed in the case of the extraction of Pb^{2+} it is noted an important affinity complexation of ligand **7** compared to ligand **3a**. Tripod **3b**, which contains an allylic double bond on the lateral arm, was observed to complex better Cu^{2+} ($E\approx$75%) and lead ($E\approx$32%) than the tripod **8**. On the other hand, the Cd^{2+} cation is not well extracted by the four ligands **3a**,**b**, **7** and **8**. In fact, the weakness of cohesion's force between the Cd^{2+} cation and coordination's sites of the studied tripods, does not allow the extraction of this cation from the aqueous solution. This result confirms our reported results.[29,32]

In the case of tripods **6a**–**e**, as obtained with **3a**,**b**, all prepared tripods present a good complexing capacity towards Hg^{2+} cations. The limit extraction values are high ($E>$50%) and does not depend on the nature of the tripods side chain. As reported in the literature, a donor atom in a side chain of lariat ethers increases the binding ability of the macrocycle.[42–44] In this sense, the comparison between **6a**, **6b** and **6c** with a donor atom in a side chain and **6e** without a donor atom showed that there is no change in the complexation percentage of Hg^{2+}. It can be concluded that the complexation of Hg^{2+} cations arises from the tripod nitrogens without any effect of the side chain, which confirms the results obtained with **3a**,**b** in the case of Hg^{2+} extraction supported by our previous studies about the strong ability of nitrogen to complex mercury.[29,32]

On the other hand, the extraction of the Cu^{2+} is affected by the nature of the substituents on the lateral chain. As reported in our previous studies,[29,32] compounds **6a** and **6c** show good affinity towards Cu^{2+} (>52%) compared to ligands **6d** and **6e**. This result may be explained by the presence of the oxygen atom on the side chain, which can participate, beside the two pyrazole nitrogens in the complexation of Cu^{2+} cations. Also, the contribution of the oxygen of the hydroxyl group of the tripod **6a** in the complexation of this metal is well promoted, due to the formation of the very stable five-membered chelating ring.[49] The less important value of extraction for the ligand **6b**, ($E\approx$35%), is probably due to the non flexible character of the secondary hydroxyl group in this structure. Tripodal ligand **6c** presents the best Cu^{2+} extraction efficiency ($E\approx$60%), slightly higher than the value observed for tripod **6a**, this is probably due to the hydrophobic nature of the molecule **6c**, which presents a phenyl group on the side chain, consequently prevents its solubility in the aqueous phase during the liquid–liquid extraction. This is also confirmed by the comparison of the Pb^{2+} extraction results obtained with **6d** and **6e**. In fact, Pb^{2+} cations are better complexated than copper by these tripods. This is due to great donor effect of the sp^2 hybridized pyrazolic nitrogen, and also to the accurate disposition of the three nitrogen atoms allowing the complexation of the metal. Compound **6a** showed a good affinity towards Pb^{2+} ($\approx$60%) compared to ligands **6b** and **6e**. This result may be explained by the participation of the hydroxyl lateral chain, beside the two pyrazole nitrogens and aminic nitrogens in the complexation of this cation. A small increase of the lead complexation value is also noted with

compounds **6c** and **6d**, probably due to their lipophilic character (phenyl). This confirms the all above-mentioned result. Finally, for the Cd^{2+} extraction, all compounds present a low extraction percentage, about 22%. Consequently, these structures do not present a high affinity towards Cd^{2+}. In fact, the weakness of cohesion's force between the Cd^{2+} cation and the coordination sites of the studied tripods, does not allow the extraction of this cation from the aqueous solution.[29,32]

3. Conclusion

New bipyrazolic tripods were prepared with different functionalized side chain by coupling of the functionalized pyrazole derivatives **2**, **4** and an appropriate primary amine derivatives via condensation or nucleophilic substitution reaction. The complexing properties of these compounds towards bivalent metal cations (Hg^{2+}, Cu^{2+}, Pb^{2+}, Cd^{2+}) and alkaline metal ions (Li^{+}, Na^{+}, K^{+}) were investigated using the liquid–liquid extraction process. These new acyclic tripod ligands present a high complexation capacity only with transition metal cations. This is schematically represented in Fig. 3.

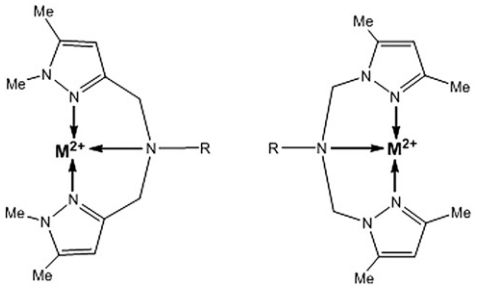


Fig. 3. A schematic representation of the bivalent metal cations complexation by the studied tripods.

A good affinity was observed with mercury, copper and lead, however a modest affinity was observed with cadmium. The affinity of the prepared tripods depends on the nature of their side chain and the best results were obtained with primary alcohol and hydrophobic phenyl groups as side chains.

4. Experimental section

4.1. General methods

All chemicals were reagent grade (Aldrich–Chemical Co.) and were used as purchased without further purification. Thin layer chromatography was carried out on silica gel pre-coated plates (Merck; 60 A° F_{254}) and spots located with (a) UV light (254 and 366 nm), (b) I_2 or (c) a basic solution of permanganate [$KMnO_4$ (3 g), K_2CO_3 (20 g) and NaOH (0.25 g) in water (300 ml)]. Flash column chromatography (FCC) was carried out on Merck silica gel 60 (230–400 mesh) according to Still et al.[50] ^1H and ^{13}C NMR spectra were recorded at 200 MHz with Varian spectrometers in deuterated solvents and are reported in parts per million (ppm) with the solvent resonance used as the internal reference. Mass spectra were determined on a Platform II Micromass instrument (ESI^+, CH_3CN/H_2O: 50/50). Elemental analyses were performed by Microanalysis Central Service (CNRS-France). Atomic absorption measurements were performed using a double beam Varian AA 20 Spectrophotometer. The following intermediates: 3-hydroxymethyl-1,5-dimethylpyrazole (**4**) and 3-chloromethyl-1,5-dimethylpyrazole (**2**) were prepared according to the procedure described in the literature.[46–48]

4.2. Synthesis procedure

*4.2.1. Synthesis of 1-[bis(1,5-dimethyl-1H-pyrazol-3-ylmethyl) amino]propan-2-ol (**3a**).* To a solution of acetonitrile (100 ml) containing 1-aminopropan-2-ol (3.0×10^{-2} mol) and sodium carbonate (18×10^{-2} mol), 3-chloromethyl-1,5-dimethylpyrazole **2** (6×10^{-2} mol) in 50 ml of acetonitrile was added slowly and the resulting mixture was stirred under reflux for 6 h. The solid crude was filtered off and the filtrate was concentrated under reduced pressure. The product was purified by flash chromatography (alumina, CH_2Cl_2/MeOH: 96/4) to afford **3a** in 85% yield. ^1H NMR ($CDCl_3$, 200 MHz): δ=1.05 (d, 3H, −CHOH−C*H*$_3$, *J*=6 Hz); 2.20 (s, 6H, pzC*H*$_3$); 2.38 (m, 2H, N−C*H*$_2$−CHOH−); 3.50 (s, 6H, C*H*$_3$−Npz); 3.65 (s, 4H, pz−C*H*$_2$−N); 3.75 (m, 1H, −C*H*OH); 5.95 (s, 2H, *H*pz); ^{13}C NMR ($CDCl_3$, 50 MHz): δ=11.5 (*C*H$_3$−pz); 20.50 (−CHOH−*C*H$_3$); 36.5 (*C*H$_3$−Npz); 51.30 (N−*C*H$_2$−pz); 61.00 (N−*C*H$_2$−CHOH); 64.20 (−*C*HOH); 106.20 (*C*pzH); 139.80 (*C*pzCH$_3$); 148.80 (*C*pz−CH$_2$N); *m*/*z*=292 $[M+1]^+$ (FAB>0); Anal. Calcd for $C_{15}H_{25}N_5O$: C, 61.85; H, 8.59; N, 24.05. Found: C, 62.16; H, 8.06; N, 24.67.

*4.2.2. Synthesis of 3-[bis(1,5-dimethyl-1H-pyrazol-3-ylmethyl) amino]prop-1-ene (**3b**).* In similar procedure, the compounds **3b** was obtained in a 75% as yield. ^1H NMR ($CDCl_3$, 200 MHz): δ=1.95 (s, 6H, pzC*H*$_3$); 3.35 (s, 6H, CH$_3$−Npz); 3.45 (s, 4H, pz−C*H*$_2$−N); 3.68 (d, 2H, N−CH$_2$−CH=; *J*=3.3 Hz); 4.85 (m, 2H, −CH=C*H*$_2$); 5.55 (m, H, −C*H*=CH$_2$); 5.75 (s, 2H, pzH); ^{13}C NMR ($CDCl_3$, 50 MHz): δ=11.25 (*C*H$_3$−pz); 36.5 (*C*H$_3$−Npz); 48.50 (N−*C*H$_2$−pz−); 53.60 (N−CH$_2$−*C*H=); 104.20 (*C*pzH); 113.50 (−CH=*C*H$_2$); 134.20 (−*C*H=CH$_2$); 139.50 (*C*pzCH$_3$); 149.20 (*C*pz−CH$_2$−N). *m*/*z*=274 $[M+1]^+$ (FAB>0); Anal. Calcd for $C_{15}H_{23}N_5$: C, 65.93; H, 8.42; N, 25.64. Found: C, 64.93; H, 7.96; N, 25.27.

*4.2.3. Synthesis of 3-[bis(1,5-dimethyl-1H-pyrazol-3-ylmethyl) amino]propanol (**6a**).* To a solution of acetonitrile (80 ml) containing 1-hydroxymethyl-3,5-dimethylpyrazole (5.04 g, 40 mmol) was slowly added 3-aminopropanol (1.5 g, 20 mmol) of in 20 ml of acetonitrile. The mixture was stirred under reflux for 5 h. The solvent was evaporated under reduced pressure. The reaction mixture was extracted with dichloromethane and washed with water to eliminate the residual amine. The organic solution was dried and the solvent was removed under reduced pressure. Tripod **6a** was obtained in an 85% yield as a viscous oil. ^1H NMR ($CDCl_3$, 200 MHz): δ=1.65 (m, 2H, CH$_2$−CH$_2$OH, *J*=5.45 Hz); 2.10 (s, 6H, CH3Pz); 2.25 (s, 6H, CH3Pz); 2.85 (t, 2H, −N−CH2−CH2−, *J*=5.7 Hz); 3.68 (t, 2H, −CH2O, *J*=5.4 Hz); 5.05 (s, 4H, N−CH2−N); 5.70 (s, 2H, PzH); ^{13}C NMR ($CDCl_3$, 50 MHz): δ=10.85 (*C*H3Pz); 13.25 (Pz-*C*H3); 35.45 (CH2−CH2O); 56.45 (N−CH2−CH2); 61.70 (CH2O); 63.55 (N−CH2−N); 105.93 (CPzH); 129.66 (CPzCH3); 132.77 (N−CPz−CH3); *m*/*z*: 292 $[M+1]^+$ (FAB>0); Anal. Calcd for $C_{15}H_{25}N_5O$: C, 61.85; H, 8.59; N, 24.05. Found: C, 62.36; H, 7.96; N, 23.87.

*4.2.4. Synthesis of 1-[bis(3,5-dimethyl-1H-pyrazol-1-ylmethyl) amino]propan-2-ol (**6b**).* In similar procedure, **6b** was obtained in a 75% yield as a white solid. Mp: 85–87 °C ($C_2H_5OC_2H_5$); ^1H NMR ($CDCl_3$, 200 MHz): δ=1.08 (d, 3H, −CHOH−CH3, *J*=6 Hz); 2.12 (s, 6H, Pz−CH3); 2.22 (s, 6H, Pz−CH3); 2.75 (m, 2H, CH2−CHOH); 3.80 (m, 1H, CHOH), 4.82 (m, 4H, N−CH$_2$−N); 5.75 (s, 2H, PzH); ^{13}C NMR ($CDCl_3$, 50 MHz): δ=11.08 (CH3Pz); 13, 05 (Pz-CH3); 21.15 (CH3−CHO); 60.15 (CHO); 66.08 (N−CH$_2$−); 67.05 (N−CH2−N); 107.25 (CPzH); 140.25 (CPzCH3); 148.12 (CPzCH3); *m*/*z*: 292 $[M+1]^+$ (FAB>0); Anal. Calcd for $C_{15}H_{25}N_5O$: C, 61.85; H, 8.59; N, 24.05. Found: C, 61.36; H, 7.86; N, 24.27.

*4.2.5. Synthesis of 2-[4-[bis(3,5-dimethyl-1H-pyrazol-1-ylmethyl) amino]phenyl}-ethanol (**6c**).* In similar procedure, **6c** was obtained

in 80% yield as a white solid: mp: 116–118 °C ($C_2H_5OC_2H_5$); ^{1}H NMR ($CDCl_3$, 200 MHz): δ=2.12 (s, 6H, Pz–CH3); 2.25 (s, 6H, Pz–CH3); 2.75 (t, 2H, CH2–CH2OH); 3.80 (t, 2H, CH2–H2OH); 5.40 (s, 4H, N–CH2–N); 5.80 (s, 2H, HPz); 5.65 (s, 2H, HPz); 6.85 (d, 2H, Hph (m), J=7.1 Hz); 7.10 (d, 2H, Hph (o), J=7.2 Hz); ^{13}C NMR($CDCl_3$, 50 MHz): δ=11.13 (CH3Pz); 13.73 (Pz–CH3); 38.56 (CH2–CH2OH); 63.78 (N–CH2–N); 63.95 (CH2–CH2OH); 105.90 (CPzH); 114.91 (CPh (o)); 121.30 (CPh (m)); 126.76 (CPh–CH2–); 129.88 (CPzCH3); 130.03 (NCPh–); 132.87 (N–CPz–CH3); m/z: 354 $[M+1]^+$ (FAB>0); Anal. Calcd for $C_{20}H_{27}N_5O$: C, 67.98; H, 7.64; N, 19.83. Found: C, 67.15; H, 7.26; N, 20.12.

*4.2.6. Synthesis of 4-[bis(3,5-dimethyl-1H-pyrazol-1-ylmethyl) amino]vinyl-1-benzene (**6d**).* In similar procedure, **6d** was obtained in a 70% yield as a white solid. Here, the reaction mixture was stirred to ambient temperature during 2 days. Mp: 101–103 °C ($C_2H_5OC_2H_5$); ^{1}H NMR ($CDCl_3$, 200 MHz): δ=2.05 (s, 6H, Pz–CH3); 2.20 (s, 6H, Pz–CH3); 5.10 (d, 1H, CH=CH2); 5.50 (s, 4H, N–CH2–N); 5.62 (d, 1H, CH=CH2); 5.75 (s, 2H, HPz); 6.62 (q, 1H, CH=CH2); 7.05 (d, 2H, Hph (o)); 7.30 (d, 2H, Hph (m)); ^{13}C NMR($CDCl_3$, 50 MHz): δ=10.20 (CH3Pz); 12.25 (Pz–CH3); 60.35 (N–CH2–N); 105.50 (CPzH); 111.50 (CH=CH_2); 119.20 (CPh (o)); 126.50 (CPh (m)); 131.20 (N–CPh); 135.20 (CH=CH2); 138.50 (CPzCH3); 145.50 (N–CPz); 147.60 (CPh–CH=CH2); m/z: 336 $[M+1]^+$ (FAB>0); Anal. Calcd for $C_{20}H_{25}N_5$: C, 71.64; H, 7.46; N, 20.90. Found: C, 72.23; H, 7.26; N, 20.18.

*4.2.7. Synthesis of N,N-bis(3,5-dimethyl-1H-pyrazol-1-ylmethyl) propanamine (**6e**).* In similar procedure **6e** was obtained in a 78% yield as viscous oil. ^{1}H NMR ($CDCl_3$, 200 MHz): δ=0.85 (t, 3H, –CH2–CH3, J=7.3 Hz); 1.46 (m, 2H, –CH2–CH3, J=7.4 Hz); 2.42(t, 2H, N–CH2–CH2, J=7.0 Hz); 2.08 (s, 6H, Pz–CH3); 2.18 (s, 6H, Pz–CH3); 5.45 (s, 4H, N–CH2–N); 5.75 (s, 2H, HPz); ^{13}C NMR ($CDCl_3$, 50 MHz): δ=10.80 (CH3Pz); 11.15 (–CH2–CH3); 13.15 (Pz–CH3); 23.45 (N–CH2–CH2); 53.45 (N–CH2–CH2); 61.58 (N–CH2–N); 105.30 (CPzH); 139.20 (CPzCH3); 145.45 (N–CPz–CH3); m/z: 276 $[M+1]^+$ (FAB>0); Anal. Calcd for $C_{15}H_{25}N_5$: C, 65.45; H, 9.10; N, 25.45. Found: C, 64.86; H, 8.96; N, 24.9.

4.3. Extraction experiments

To a solution of 7×10^{-5} M of tripod in CH_2Cl_2 (50 ml) was added an aqueous solution (50 ml) of metal nitrates (7×10^{-5} M). The mixture was stirred for 2 h at room temperature. The percentage limit of extraction was determined by measuring the concentration of cations in the aqueous solution by atomic absorption. The temperature and pH remained constant for all the experiments (25 °C; pH=7).

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